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Performance Testing of the DiPerna Sweeper

Mason and Hanger-Silas Mason Co., Inc.
Leonardo, NJ

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PERFORMANCE TESTING OF THE DiPERNA SWEEPER

by

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Contract No. 68-03-2642

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16. ABSTRACT

The DiPerna Sweeper, a partial-vacuum oil skimmer, was tested in a two-week test program conducted at the U.S. Environmental Test Tank (OHMSETT) in Leonardo, New Jersey. Forty-three oil recovery tests were run. The object of the program was to establish a range of best performance for the skimmer under various environmental conditions in light and heavy oils.

The DiPerna Sweeper is a self-contained, floating oil skimmer that can operate in either a stationary or advancing mode. Its principle of operation is based upon drawing oil and water into a sealed container by creating a slight vacuum in the container. A floating weir serves as the inlet. The partial vacuum is created by pumping fluid from the sealed container. The continer serves as an oil/water separator. Separate pumps draw water from the bottom of the vessel while others draw oil from the top.

The device was able to recover over 75% of the oil presented to it in calm water at tow speed up to two knots. Performance decreased in waves. Modifications are suggested to improve such performance. The separator functioned well. In one case, the oil offloaded from the skimmer was 95% free of water.

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FOREWORD

The U.S. Environmental Protection Agency was created because of increasing public and government concern about the dangers of pollution to the health and welfare of the American people. Noxious air, foul water, and spoiled land are tragic testimonies to the deterioration of our natural environment. The complexity of that environment and the interplay of its components require a concentrated and integrated attack on the problem.

Research and development is that necessary first step in problem solution; it involves defining the problem, measuring its impact, and searching for solutions. The Municipal Environmental Research Laboratory develops new and improved technology and systems to prevent, treat, and manage wastewater and solid and hazardous waste pollutant discharges from municipal and community sources, to preserve and treat public drinking water supplies, and to minimize the adverse economic, social, health, and aesthetic effects of pollution. This publication is one of the products of that research and provides a most vital communiations link between the research and the user community.

This report describes full-scale testing of a vacuum-type skimmer designed by James DiPerna. The design features a non-turbulent oil and water collection system and a built-in oil/water separator. Further information may be obtained through the Solid & Hazardous Waste Research Division, Oil and Hazardous Materials Spills Branch, Edison, New Jersey.

Francis T. Mayo
Director
Municipal Environmental Research Laboratory
Cincinnati

ABSTRACT

The DiPerna Sweeper, a partial-vacuum oil skimmer, was tested in a two-week test program conducted at the U.S. Environmental Protection Agency's Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) in Leonardo, New Jersey. Forty-three oil recovery tests were run. The object of the program was to establish a range of best performance for the skimmer under various environmental conditions in light and heavy oils.

The DiPerna Sweeper is a self-contained, floating oil skimmer that can operate in either a stationary or advancing mode. Its principle of operation is based upon drawing oil and water into a sealed container by creating a slight vacuum in the container. A floating weir serves as the inlet. The partial vacuum is created by pumping fluid from the sealed container. The container serves as an oil/water separator. Separate pumps draw water from the bottom of the vessel while others draw oil from the top.

The device was able to recover over 75% of the oil presented to it in calm water at tow speeds up to two knots. Performance decreased in waves. Modifications are suggested to improve such performance. The separator functioned well. In one case, the oil offloaded from the skimmer was 95% free of water.

This report was submitted in fulfillment of Contract No. 68-03-2642, Job Order No. 58 by Mason & Hanger-Silas Mason Co., Inc., under the sponsorship of the U.S. Environmental Protection Agency. This report covers a period from 14 May 1979 to 25 May 1979.

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ABBREVIATIONS AND SYMBOLS

EPA	--Environmental Protection Agency
kg	--kilogram
kt	--knots
m	--meters
mm	--millimeters
m^3	--cubic meters
m^3/hr	--cubic meters per hour
ND	--no data
HC	--harbor chop wave condition (non-regular wave condition achieved by allowing waves to reflect off all tank side walls)
OHMSETT	--Oil and Hazardous Materials Simulated Environmental Test Tank
ORR	--oil recovery rate = volume of oil recovered by the skimmer per unit time (m^3/hr)
RE	--recovery efficiency = percent of oil in the oil/water mixture that is recovered from the water surface by the skimmer (%)
TE	--throughput effficiency = percent of oil that enters the skimmer and is recovered from the water surface (%)
s	--seconds

LIST OF CONVERSIONS

METRIC TO ENGLISH

To convert from	to	Multiply by
Celsius	degree Fahrenheit	$t_C = (t_F-32)/1.8$
joule	erg	1.000 E+07
joule	foot-pound-force	7.374 E-01
kilogram	pound-mass (lbm avoir)	2.205 E+00
meter	foot	3.281 E+00
meter	inch	3.937 E+01
meter^2	foot^2	1.076 E+01
meter^2	inch^2	1.549 E+03
meter^3	gallon (U.S. liquid)	2.642 E+02
meter^3	liter	1.000 E+03
meter/second	foot/minute	1.969 E+02
meter/second	knot	1.944 E+00
meter^2/second	centistoke	1.000 E+06
meter^3/second	foot^3/minute	2.119 E+03
meter^3/second	gallon (U.S. liquid)/minute	1.587 E+04
newton	pound-force (lbf avoir)	2.248 E-01
watt	horsepower (550 ft lbf/s)	1.341 E-03

ENGLISH TO METRIC

centistoke	meter^2/second	1.000 E-06 degree
Fahrenheit	Celsius	$t_C = (t_F-32)/1.8$
foot	meter	3.048 E-01
foot^2	meter^2	9.290 E-02
foot/minute	meter/second	5.080 E-03
foot^3/minute	meter^3/second	4.719 E-04
foot-pound-force	joule	1.356 E+00
gallon (U.S. liquid)	meter^3	3.785 E-03
gallon (U.S. liquid)/minute	meter^3/second	6.309 E-05
horsepower (550 ft lbf/s)	watt	7.457 E+02
inch	meter	2.540 E-02
inch^2	meter^2	6.452 E-04
knot (international)	meter/second	5.144 E-01
liter	meter^3	1.000 E-03
pound force (lbf avoir)	newton	4.448 E+00
pound-mass (lbm avoir)	kilogram	4.535 E-01

ACKNOWLEDGMENTS

Mr. James DiPerna and Brewer Dry Dock Co. are gratefully acknowledged for supplying the oil skimmer and technical guidance during the tests.

John S. Farlow, Chief of the Oil Spills Staff for the U.S. Environmental Protection Agency, provided valuable assistance throughout the project.

Many helpful suggestions and ideas were given by Michael G. Johnson, test director. Extra time and effort was devoted by Gary F. Smith to obtain data results quickly and accurately. These and other Mason & Hanger-Silas Mason Co., Inc. personnel deserve thanks for their professional and innovative support.

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SECTION 1

INTRODUCTION

The DiPerna Sweeper, shown in Figure 1 was designed by Mr. James DiPerna of Staten Island, New York, and built by Brewer Dry Dock Company, also of Staten Island, New York. In April 1979, the skimmer was transported from the shipyard to OHMSETT on a common-carrier flatbed tractor trailer. The original gravity-flow design was modified to a partial vacuum design at OHMSETT under the direction of Mr. DiPerna. The merits of the conversion were demonstrated using a small model built by Mr. DiPerna (Figure 2). The modifications did not affect the basic non-mixing oil/water collection principle. Other modifications suggested by Mr. DiPerna regarding removing the skimming head and altering the skimmer to allow the fluid to flow over a weir attached to the separator were not acted upon at this time.

On 14 May, the skimmer was lifted into the test tank where 43 oil recovery tests were run with light and heavy oils, which are described in Appendix B. On 25 May, the device was removed from the tank. All performance testing was conducted at OHMSETT by the operating contractor Mason & Hanger-Silas Mason Co., with the guidance of the U.S. EPA Project Officer.

Figure 1. The DiPerna Sweeper being lifted into the test tank.

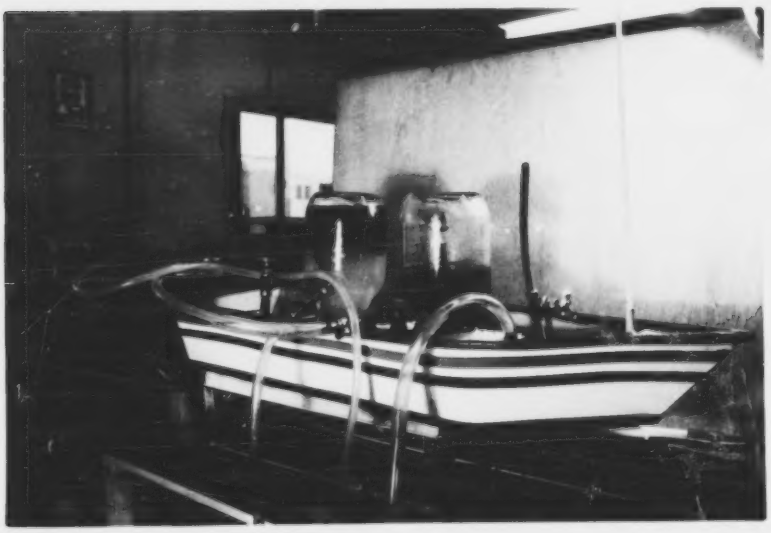

Figure 2. Model demonstration of the oil collection and separation techniques of the DiPerna Sweeper. Note the clean water beneath the oil in the second compartment.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

CONCLUSIONS

The DiPerna Sweeper proved effective in recovering light and heavy oils at tow speeds up to 2.0 knots. Based upon samples taken at the oil offloading pump outlet the skimmer has the capability of offloading the collected oil over 95% free of water. This is due to the method of drawing oil and water into the skimmer without mixing them and offloading oil from top of the collected fluid and water from the bottom.

The best performance of the skimmer obtained during the two week test program is listed below (TE is in percentile; ORR is in m^3/hr). RE samples were not taken on every test and so do not appear in the chart.

	0.5 kt		1.0 kt		1.5 kt		2.0 kt		2.5 kt	
	TE	ORR*	TE	ORR	TE	ORR	TE	ORR	TE	ORR
Calm water	95.0	12.7#	96.2	26.3#	95.1	38.0#	75.3	40.2	33.2	22.1
0.3 m HC	44.1	5.3	72.8	19.4	46.4	18.5	27.3	14.6	ND	ND
0.3 m reg. wave	ND	ND	38.3	10.0	23.5	9.4	21.1	11.3	21.0	14.0

*ORR values are corrected to 12 mm thick oil slicks by multiplying the measured ORR by 12 mm and dividing by the actual slick thickness.

#One water discharge pump (70 m^3/hr) was used. All other tests used four pumps (125 m^3/hr total).

The discrete samples taken at the pump outlet resulted in RE values of 95.5% at 1 knot in calm water and 88% at 0.5 knots in the 0.3 m harbor chop. Further discussion of RE is taken up in the Discussion of Results portion of this report.

The skimmer performed best in heavy oil in calm water. Waves caused drastic reductions in performance with regular wave head seas resulting in the poorest performance.

The greater the number of pumps removing fluid from the skimmer, the better the device performed. The primary objective to improve performance was to get as much of the oil slick into the device as possible and not worry whether some oil was discharged out the stern with the water.

The shovel-nose design of the skimming head and its attachment to the main body of the device via a large stiff hose was not conducive to optimum wave following. Overall performance in waves could be substantially improved with the proper skimming head and inlet hose.

The main portion of the skimmer was stable and generally unresponsive to waves. This was due to the deep, water-filled keel and the flotation chambers on both sides of the vessel.

RECOMMENDATIONS

A redesign of the skimming head and inlet hose should be undertaken to improve wave response of the hose and head system, to improve the skimming head water ballasting system, to prevent wave splashover and to prevent turbulence and headwave production while under tow in calm water and in waves.

The main portion of the skimmer should be outfitted with larger pumps than those tested. A pump with a capacity of about 200 m^3/hr should be used to remove the water from the bottom of the vessel, while a 50 m^3/hr positive displacement pump should be used for offloading oil and removing air from the top of the skimmer.

The oil/water separator should be enlarged. A longer residence time and a more stable vessel would result if the lower portion of the oil/water separation compartment were extended beyond the center to the port and starboard sides to form a rectangular cross-section.

SECTION 3

DEVICE DESCRIPTION

The original design of the DiPerna Sweeper consisted of a gravity-flow API oil/water separator mounted between two flotation chambers (Figures 3 and 4). A segregated floating head with an overflow weir, connected to the main portion of the skimmer by a 20-cm diameter hose, served as a fluid inlet (Figure 5). Oil and water were drawn into the skimmer over the weir by lowering the water level inside the device below the outside waterline. This was accomplished by pumping water from the bottom of the separator. Oil collected in the first compartment and was routed to a rear compartment where it was offloaded by a small pump. The water was removed from the bottom of the separator in the second compartment. This design allowed the use of less than half of the separator volume since a good portion of the separator extended above the mean waterline. Modifications to seal the top of the separator off from the atmosphere and reroute pump piping were carried out while the skimmer awaited testing at OHMSETT (Figures 6 and 7). The changes permitted the use of the entire volume of the oil/water separator and simplified the offloading of collected oil.

With the top of the separator sealed, a partial vacuum could be induced inside the separator by pumping the air out from the top of the chamber. Fluid allowed over the inlet weir filled the evacuated area. Thus a flow of fluid entering over the weir and exiting one or more pumps could be maintained even though the fluid level inside the separator was above the waterline. Water was still removed from the lower rear of the separator, but the oil outlets were relocated to ports welded flush with the sealed deck. The design utilized the entire volume of the oil/water separator with a minimum increase in vessel draft.

The segregated floating head was not modified from the original design. The design and concept of a light, wave-following skimming weir that was separate from the main body of the skimmer appeared sound and did not warrant change. The head was detached from the separator so it could follow waves, maintaining the weir at the desired depth. The swamping of the weir and sump by waves would be avoided if it performed as designed. Heretofore, the skimming head had not been tested in either a model or in full scale. Chambers and valves were incorporated into the head to permit ballasting with water. The sweep width of the head was 1.2 m, while the width of the weir is 0.5 m. Directly behind the weir was a small sump which leads to the large hose connecting the head to the skimmer. Additional skimming heads could be attached to the skimmer using small ports welded to the fluid inlet pipe. These heads could be used at a distance from the skimmer and thus collect oil from shallow areas or under piers while the main skimmer sits in deep, open water.

Fluid is drawn into the skimmer by pumping water from the lower rear of the separator. It enters the separator chamber at the front directly beneath the deck. The unmixed oil is delivered to the top of the separator where it floats, while the

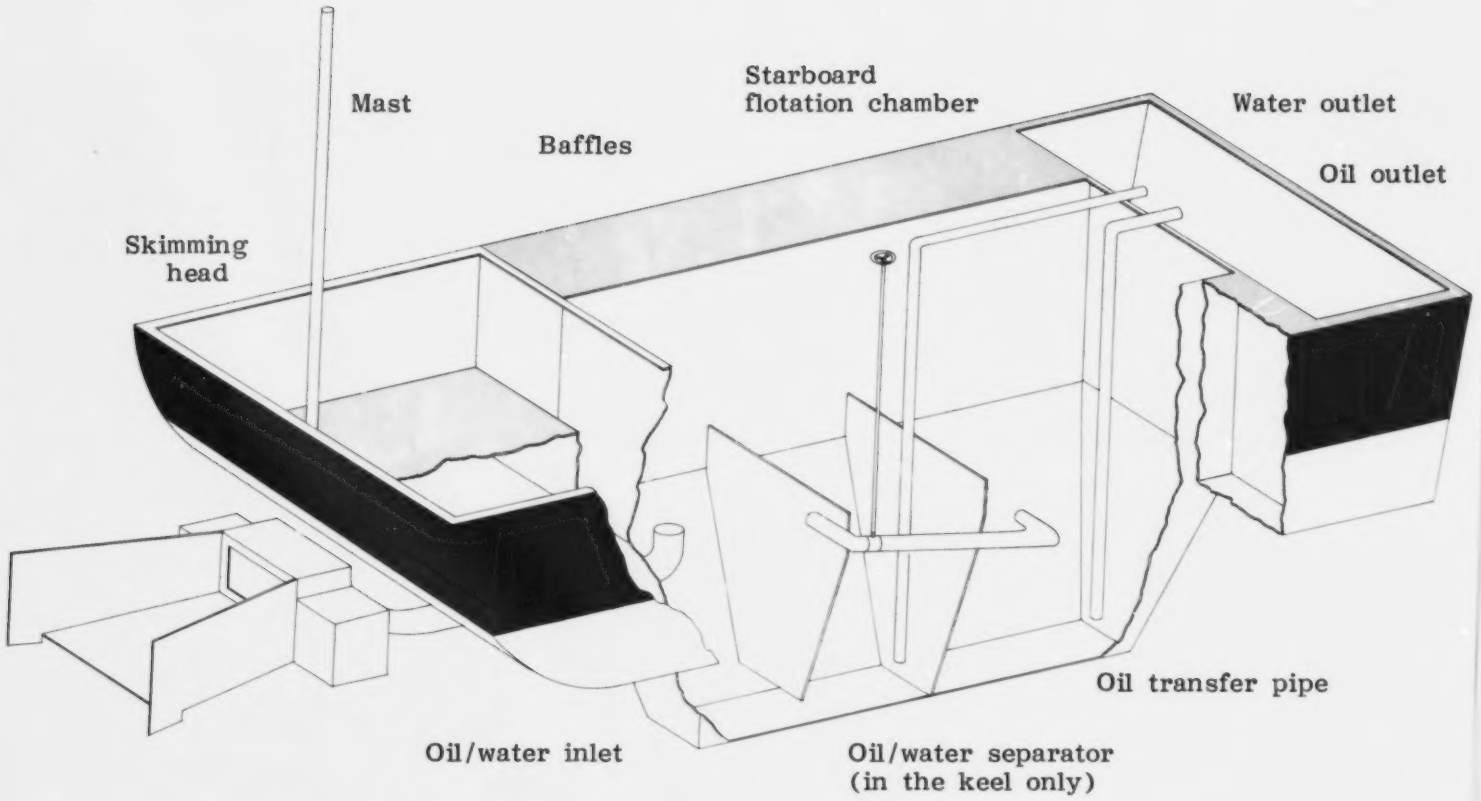

Figure 3. Cutaway view of original DiPerna Sweeper design.

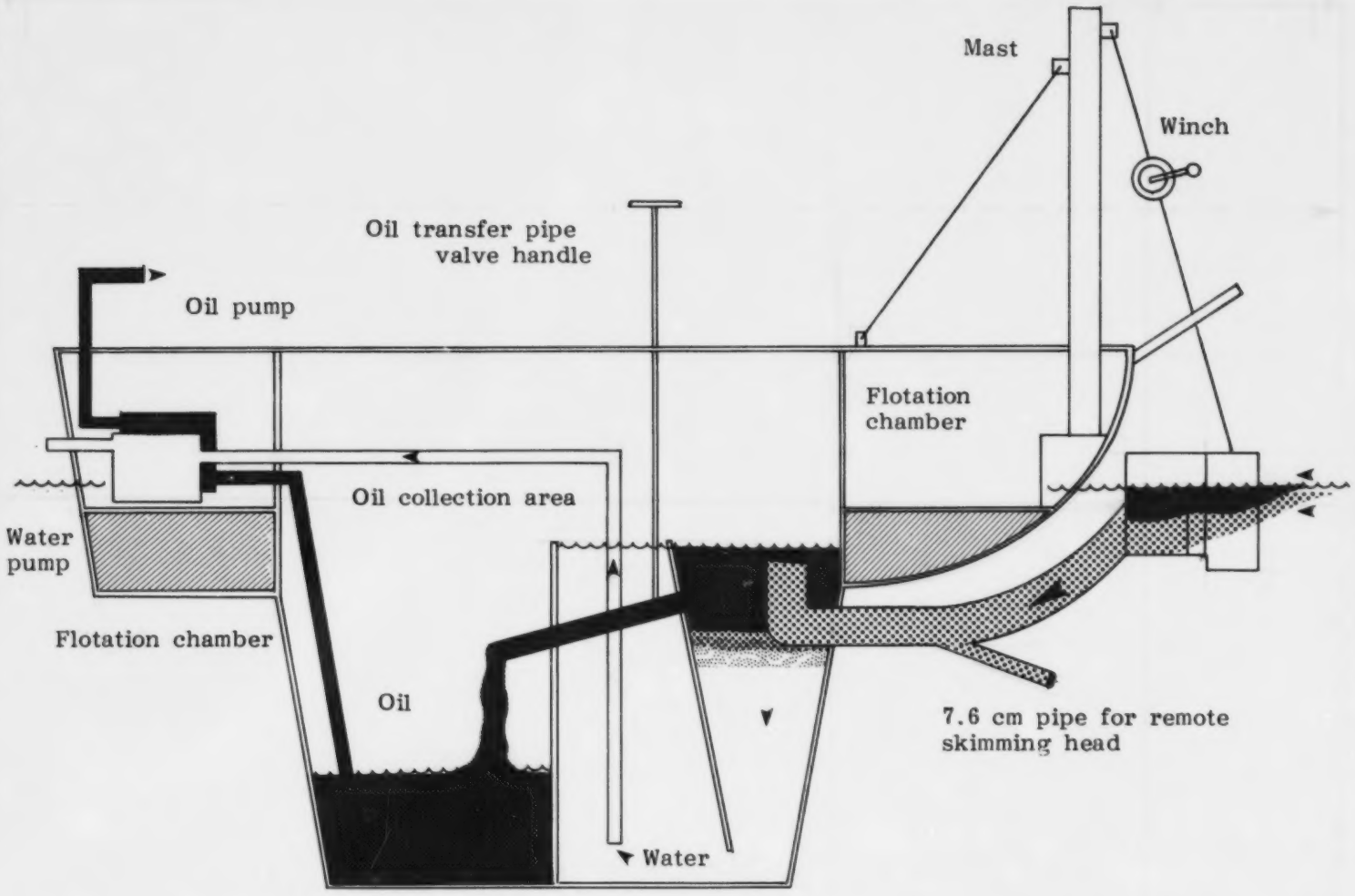

Figure 4. Section view of original DiPerna Sweeper design depicting the flow of oil and water.

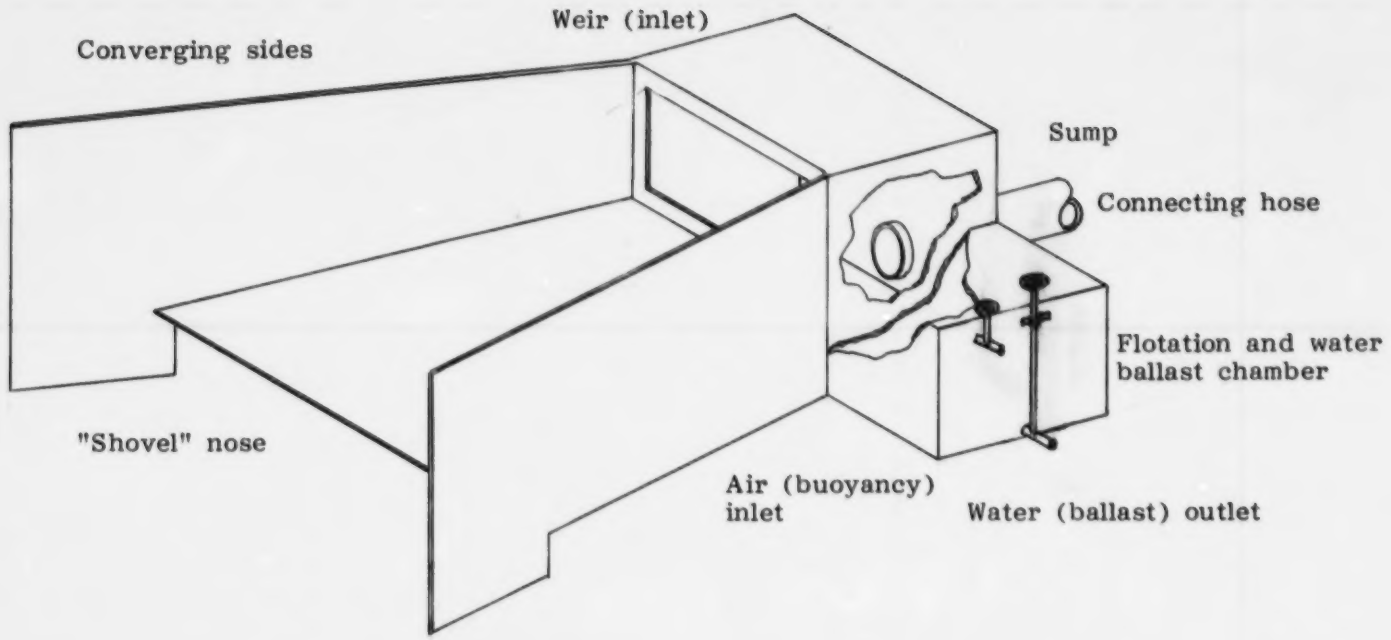

Figure 5. Isometric view of the floating skimming head.

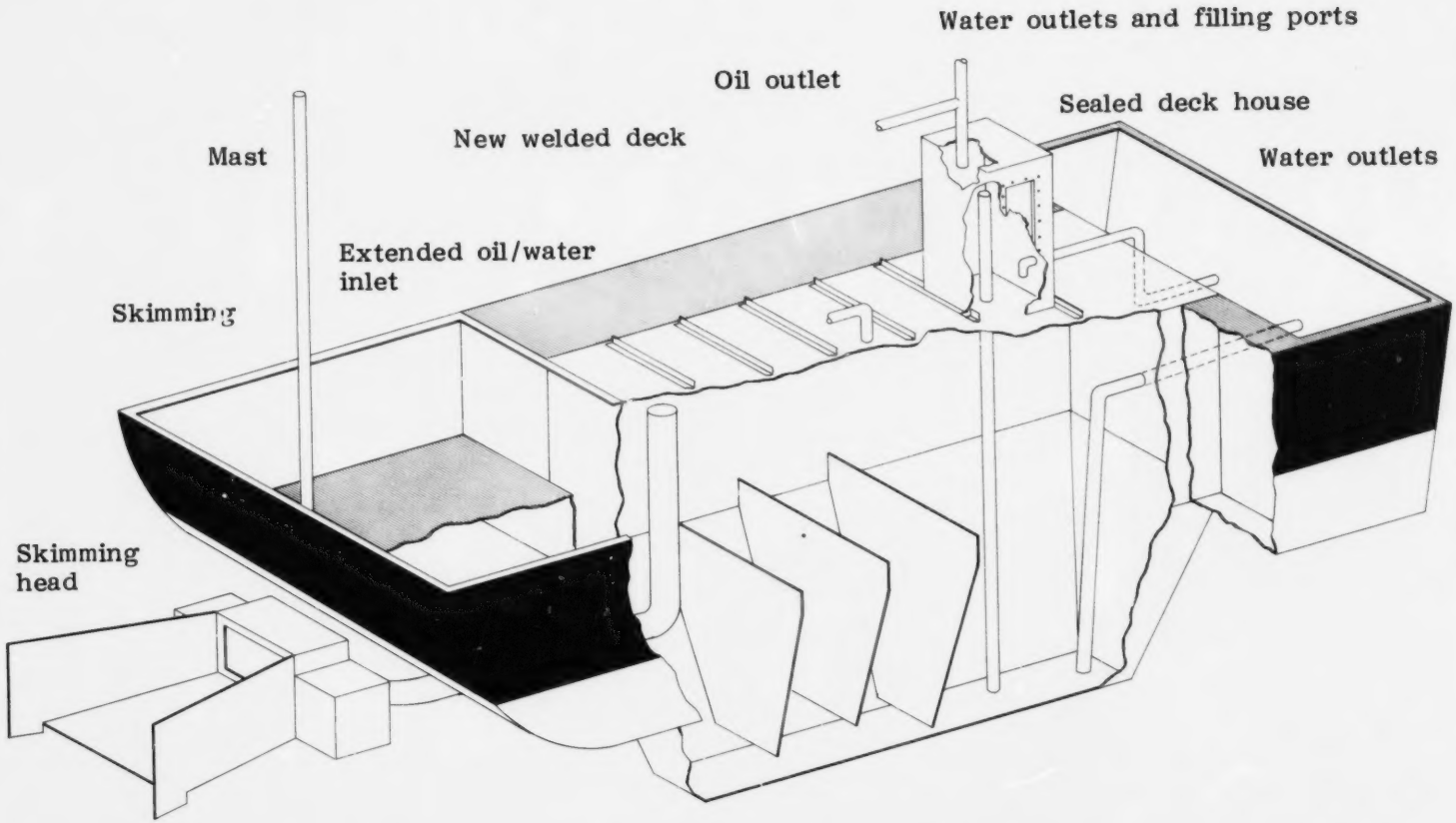

Figure 6. Cutaway view of the modified DiPerna Sweeper.

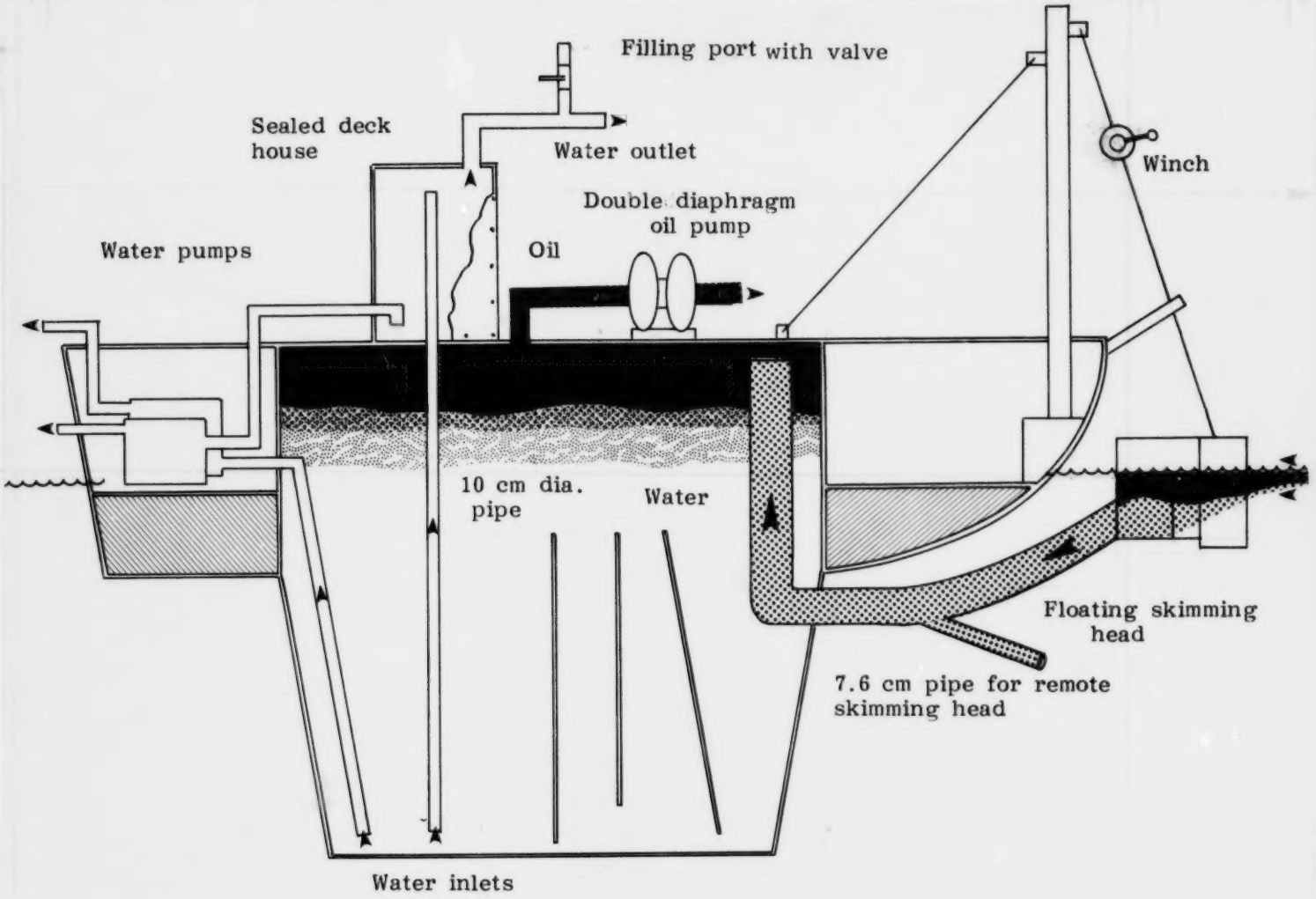

Figure 7. Section view of modified DiPerna Sweeper depicting the flow of oil and water.

water seeks the lower level. In this manner, oil and water mixing is minimized. The volume of the separator is 6.3 m^3. The residence or allowable separation time of the oil and water in the separator can be varied depending upon the offloading pumping rate. The pumps used in the OHMSETT tests had a combined flow rate of about 120 m^3/hr. Residence time (190 s) with all of the pumps operating appeared more than adequate.

A small, sealed deck house with plexiglas windows was placed on the skimmer with a pipe running from it down through the deck to the keel of the separator. Water was drawn from the house and thus fluid flowed up the pipe to replace it. The windows allowed the operator to see when oil was being drawn up the pipe and thus signal him to slow the pump rate or to offload oil.

The vessel tested had an overall length of 5.5 m, a beam of 2.9 m, a draft of 1.7 m and a freeboard of 1 m. The vessel weighed about 3000 kg.

SECTION 4

TEST DESCRIPTION

EQUIPMENT

The DiPerna Sweeper was lifted into the test tank and rigged for testing between the main and auxiliary bridges (Figures 8, 9, and 10). Tow lines were tied from the main portion of the skimmer to the main bridge. Tow back lines were attached to the rear of the skimmer and secured to the auxiliary bridge. Oil guide booms were strung between the floating skimmer head and tow points mounted on the main bridge. The booms guided the distributed oil slick to the floating skimmer head and prevented it from spreading beyond the sweep width of the head. The original, lightweight oil guide booms were later replaced with larger, heavy duty booms when it was determined that waves caused oil to be washed over and under the small booms during test runs.

The skimming head was ballasted using SCUBA diver weights and guyed with ropes to the skimmer's mast in order to maintain a proper orientation of the intake weir. Water ballasting was tried but since there was only one compartment in each side of the head, the water would flow to the rear when the head tipped back. This caused the shovel nose of the head to rise up out of the water. The head would remain in that position unless it was reoriented by the skimmer operator. The stiff, heavy inlet hose running from the rear of the skiming head to the main portion of the skimmer also caused the skimming head to pitch rearward and sink. A wire rope was run from the skimming head to a winch on the skimmer's mast. The depth of the skimming head (weir cut) was regulated by operating the winch.

The separator portion of the skimmer was also ballasted to raise the oil offloading port. A total of 340 kg of ballast was placed in the starboard bow. The skimmer operator also stood near the ballast when the oil was offloaded. This ensured the collected oil contained beneath the deck would flow to the desired location so it could be easily and completely pumped off.

A centrifugal pump (16 m^3/hr) for discharging water and a double diaphragm air-driven pump (32 m^3/hr) for offloading oil were added to the skimmer to supplement the pumps which arrived with the skimmer in order to increase the fluid intake over the weir. This resulted in a total flow rate of about 120 m^3/hr. In calm water the additional pumping markedly increased performance at tow speeds above 1.5 knots.

The test oils were distributed from an overflow weir manifold on the main bridge. A splash plate and laydown cloth were used to gently lay the oil on the water so all of the oil would be on the surface when the skimmer encountered the slick. Most test were run with a nominal 12-mm slick thickness. The measured ORR values were later "corrected" to this condition by multiplying by 12 mm and diving by the actual slick thickness.

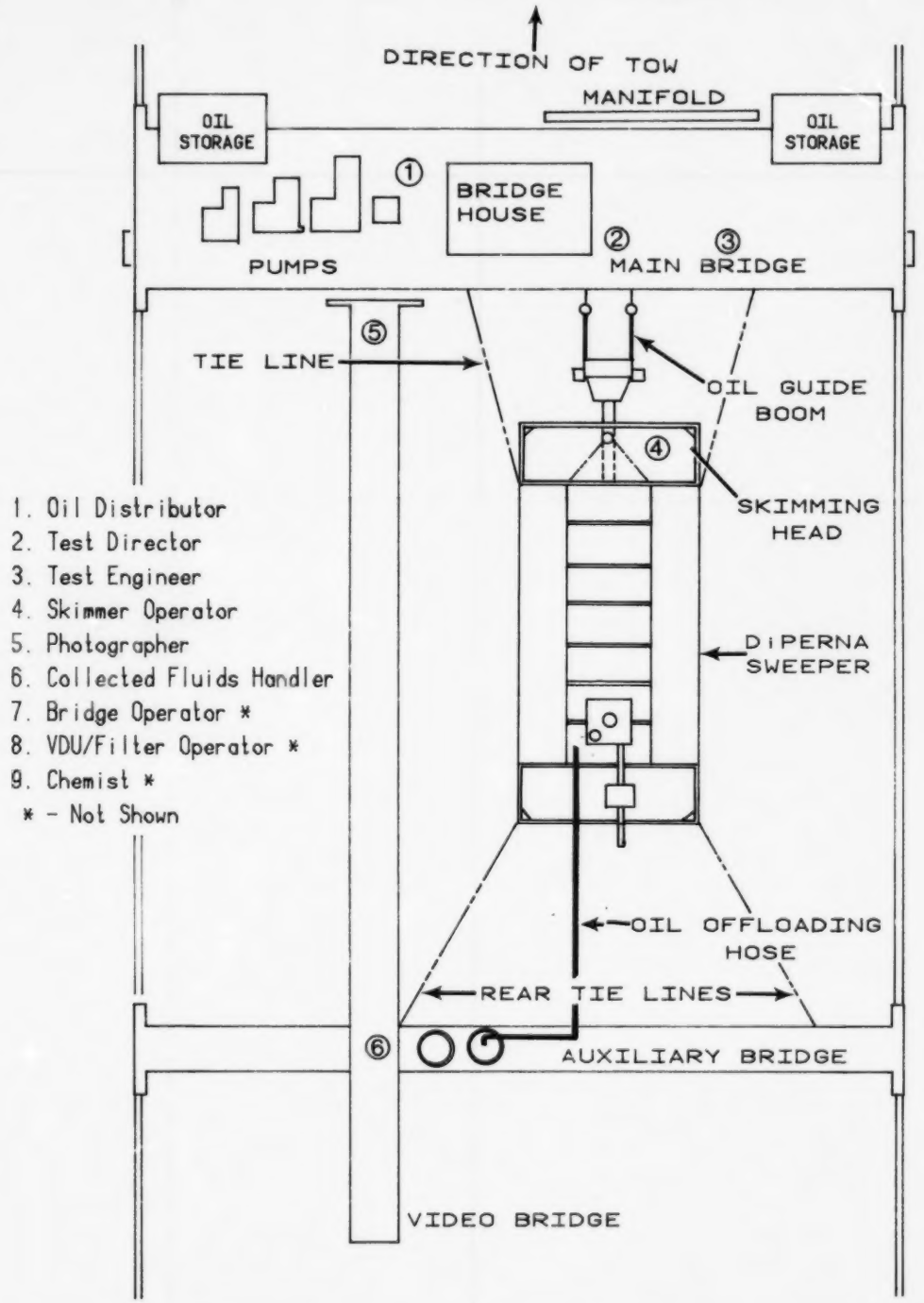

Figure 8. Test set up for the DiPerna Sweeper.

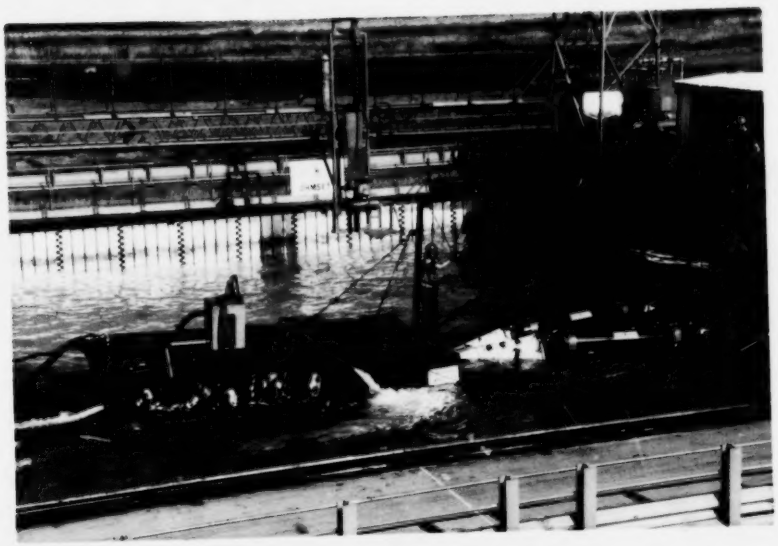

Figure 9. View of starboard side of DiPerna skimmer during a calm water test.

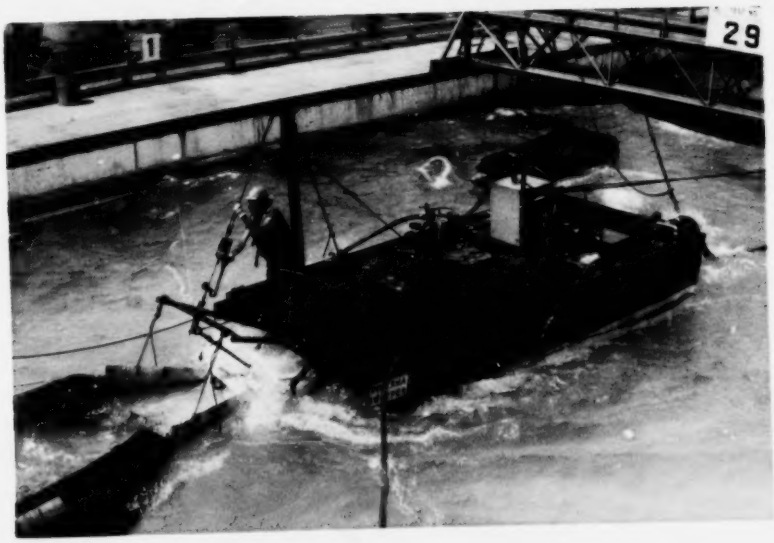

Figure 10. View of port side of DiPerna skimmer during a wave test.

TEST PLAN

A test matrix was designed to fully evaluate and optimize device performance within the allotted tank time. Tow speed, oil type, wave condition, and pumping rate were evaluated for their effect on throughput efficiency (TE) and oil recovery rate (ORR), Tables 1 and 2. Recovery efficiency was not specifically recorded every test due to having to offload a great deal of water with the oil after each test. Some discrete samples were taken as the oil was pumped into the collection barrels, and the samples were analyzed for oil water content.

To supplement the quantitative data, observations were recorded in logs, and visual recordings were made on video tape, 35 mm still photographs, and 16 mm movies.

A successful test run required that proper procedures be followed before, during, and after the test. The test procedures are listed below:

TEST PROCEDURES FOR DiPERNA TEST

(1) Set oil distribution rate.

(2) Obtain desired waves.

(3) Lower skimming head to the 20-cm mark to ensure flow into the skimmer.

(4) Start skimmer pump(s).

(5) Skimmer operator move to test position near the skimming head.

(6) Remove all oil from between oil herding booms, raise skimming boom on main bridge, and begin tow.

(7) Adjust skimmer head to proper depth (usually 6 to 7 cm). The depth should be the minimum needed to prevent oil shedding and draining of the skimming head sump.

(8) Begin oil distribution.

(9) Stop oil distribution after allotted time.

(10) Continue towing 30 m past the oil slick. Hose oil remaining in front of the skimming head into the head. Stop the wave generator if it was used during the test.

(11) Stop the bridge and lower the skimming boom(s) on the main and auxiliary bridges. Secure the water discharge pumps on the skimmer.

(12) Lower the skimming head to the 20-cm mark (operator remains in the front, starboard of the vessel).

(13) Start oil offloading (double diaphragm) pump if it was not used during the tow.

(14) When clean water is seen coming from the outlet shut the pump and compressor off.

(15) Prepare equipment and personnel for the next test.

The fluid collected by the skimmer was offloaded into translucent barrels on the auxiliary bridge and allowed to settle and separate about 10 minutes, the volume was measured, and the water was drained from the bottom. The remaining fluid was measured and mixed with a small electric outboard motor for 5 minutes and then sampled for laboratory analysis. The percentage of oil in the sample was found by a centrifuging process. The value was applied to the fluid volume in the barrel when the sample was taken to calculate the total oil collected by the skimmer.

TABLE 1. TEST RESULTS OF THE DiPERNA SWEEPER IN HIGH VISCOSITY OIL

Test no.	Tow speed (knots)	Waves (m x m)	Slick thick (mm)	Weir depth (cm)	TE (%)	ORR (m^3/hr)	Comments
SD 3	0.5	Calm	11.7	6.35	95.0	12.4	140 kg ballast on vessel, wts and ropes on head
1	0.5	Calm	12.4	6.35	91.3	12.6	Good test
2	0.5	Calm	12.4	6.35	93.7	12.9	No losses seen in underwater film footage
3	0.75	Calm	13.2	6.35	91.8	20.1	Ballast on skimmer raised to 340 kg
4	0.75	Calm	13.4	6.35	95.0	20.8	Good test, water discharge clean of oil
5	1.0	Calm	12.9	6.35	94.5	27.2	Small losses less than 1% at boom attachment points
6	1.0	Calm	12.8	7.62	84.3	24.1	Oil not hosed in at the end of the test, 95% RE at oil/water outlet
7	1.0	Calm	12.8	6.35	96.2	27.4	Good test
8	1.25	Calm	12.9	6.35	97.2	28.1	Oil shedding seen from the front
9	1.25	Calm	10.4	6.35	95.1	27.5	Same as test no. 8
10	1.50	Calm	9.4	6.35	95.1	29.8	Good test
11	0.5	0.3 m HC	11.9	varied	25.7	3.4	Wave reflection down nose of skimming head washed oil away, 88% RE at oil/water outlet
12	1.25	Calm	10.1	7.62	93.8	26.5	Good test

(Continued)

TABLE 1. (Continued)

Test no.	Tow speed (knots)	Waves (m x m)	Slick thick (mm)	Weir depth (cm)	TE (%)	ORR (m^3/hr)	Comments
13	1.5	Calm	12.6	7.62	87.4	36.5	A good deal of entrainment from the skimming head
14	2.0	Calm	13.1	7.62	46.9	27.4	Entrainment much worse
15	2.0	Calm	12.8	6.35	55.9	31.8	Large oil losses seen due to shedding
16	2.5	Calm	12.2	6.35	23.4	15.9	Some oil escaped under the port boom
17	0.5	0.3 m HC	12.8	varied	30.7	4.4	Main skimmer and head out of phase due to waves, jerking action on head caused oil losses
18	2.0	Calm	8.7	6.35	34.3	13.3	New pump on skimmer failed in middle of test
19*	2.0	Calm	9.7	10.16	30.2	13.1	Four pumps used - lowered weir to gain flow
*Four pumps were used from this test on except for tests 24, 39, 40, 41, and 42.							
20	2.0	Calm	---	---	---	---	Aborted due to oil distribution pump failure
21	2.0	Calm	12.4	11.43	75.3	41.6	Good test
22	2.0	Calm	12.1	11.43	69.5	37.3	Skimming head rising and falling as it emptied and filled again
23	0.5	0.3 m HC	12.0	varied	44.1	5.3	Larger booms used to guide oil to the skimmer
24	0.75	0.3 m HC	11.7	varied	45.2	8.9	One pump used to compare results

(Continued)

TABLE 1. (Continued)

Test no.	Tow speed (knots)	Waves (m x m)	Slick thick (mm)	Weir depth (cm)	TE (%)	ORR (m^3/hr)	Comments
25	0.75	0.3 m HC	12.0	varied	80.7	16.2	Turbulence caused by skimming head action, some oil reached the water discharge inlet
26	1.0	0.3 m HC	12.0	varied	72.8	19.4	86% RE determined from grab sample at oil/water outlet
27	1.5	0.3 m HC	12.5	varied	46.4	19.3	Skimmer head sump drained after each wave, good test
28	2.5	Calm	12.2	12.7	33.2	22.5	Good test, vortices in front of head caused losses
29	2.0	0.3 m HC	11.8	varied	27.3	14.4	Waves and oil splashed over skimming head
30	0.5	0.4x11.6	---	---	---	---	Aborted due to lack of oil entering skimming head
31	1.0	0.4x11.6	12.6	varied	38.3	10.5	Waves reflected from head washed oncoming oil slick away
32	1.5	0.4x11.6	12.5	varied	23.5	9.8	Same as test no. 31
33	2.0	0.4x11.6	12.5	varied	21.1	11.8	Air entered skimmer because the head drained completely at times
34	2.5	0.4x11.6	12.6	varied	21.0	14.7	Losses due to shedding more than splashover, water discharge clean of oil

TABLE 2. TEST RESULTS OF THE DiPERNA SWEEPER IN LOW VISCOSITY OIL

Test no.	Tow speed (knots)	Waves (m x m)	Slick thick (mm)	Weir depth (cm)	TE (%)	ORR (m^3/hr)	Comments
35	0.5	Calm	---	---	---	---	Test aborted due to obstruction in water jet nozzle which controlled the slick width
36	0.5	Calm	12.2	10.2	83.1	11.1	Water discharge lightly colored by oil
37	1.0	Calm	---	---	---	---	Aborted, water discharge pump ran out of gas
38	1.0	Calm	12.4	10.2	73.5	19.9	Vortices formed at boom attachment points, oil drawn underwater and lost
39	1.5	Calm	12.2	10.2	78.0	31.8	Smallest pump failed, three pumps in service
40	2.0	Calm	12.5	12.7	32.5	18.1	Three pumps in service, only 5 or 6% decrease in pumping rate of 4 pumps
41	2.5	Calm	12.3	11.4	8.3	5.7	Great deal of entrainment from skimming head
42	1.0	0.4x11.6	12.7	varied	7.2	2.0	Oil pushed away from head by reflection waves
43	1.0	0.4x11.6	---	---	---	---	Aborted due to break in oil boom tie line

SECTION 5

DISCUSSION OF RESULTS

DEVICE DISCUSSION

The DiPerna Sweeper proved to be of simple and effective design incorporating no machinery necessary for oil recovery except pumps. The skimmer can be pushed, towed, or self-propelled during its oil collection operations. The force of the water from the pump discharge off the rear of the skimmer was enough to propel the device forward at about 0.25 to 0.5 knots. Such a forward speed may be suitable for tank testing but would not be practical for field use.

The performance and effects of the individual components of the device will be discussed systematically beginning at the fore of the device and working aft. The reader should remember that the skimmer was chiefly designed to be attached to oil booms and collect oil as winds and currents would drive the oil to the skimming head and it is not intended for high-speed skimming.

Floating Skimming Head

If the skimming head is to be retained, a major redesign is necessary. The shovel-nose design of the head caused many problems in the presence of waves. It acted as a damper to slow the inlet weir's wave response; it produced turbulence in the oil slick to be encountered when it heaved above the waterline; it provided a spillway for the excess oil and water which was washed up to the weir but could not enter. As the fluid ran down the nose it mixed vigorously and pushed the oncoming oil slick away from the head. The best solution seemed to be a deeper weir cut in waves, so the shovel nose would never rise high enough to cause problems. Under tow in both calm water and waves, the shovel nose acted as a diving plane causing the weir to sink below the calm-water setting and the head to pitch forward. The nose also caused problems with water ballasting the head. If the ballast water drained to the rear due to a rearward pitch of the head, the nose became a forward buoyancy chamber which maintained the head in the tilted position. SCUBA diver weights, guy wires and a wire rope cable to a winch on the mast provided the ballast and kept the weir at the desired setting for the tests. However, an unfortunate interference occurred due to the use of the guy ropes and the wire rope on the skimming head. When a wave trough was encountered the ropes restricted the downward travel of the head causing a sudden stop. This prevented the weir from maintaining a constant depth and allowed water and oil to flow down off the nose onto the approaching oil slick. However, without the ropes the movements of the skimming head from side to side and pitching forward would have made oil collection much more difficult. The removal of the shovel nose from the skimming head and judicious placement of flotation and ballast should solve most of the above problems. A feature which the skimming head lacked was a vertical plate to prevent waves from splashing over the head and thus losing oil. Finally, the

weir tended to raise up above the waterline when the fluid in the head sump was pumped out and thus restricted flow over the weir. However, if the sump did not drain somewhat in between waves the next wave would swamp the sump and oil would be washed away from the weir. A self-compensating weir lip or inlet valve could be built into the skimming head to prevent such starving of fluid flow.

Oil/Water Inlet Hose

The hose used in the tests was too heavy and too stiff to allow the skimming head to act independently of the main body of the skimmer. If the skimmer operator changed his location on the deck of the vessel the slight tilt of the vessel would twist the hose and alter the attitude of the skimming head. The flotation of the skimming head was not enough to freely move the inlet hose as it responded to oncoming waves.

Oil/Water Separator

The conversion of the separator from gravity flow to partial vacuum made available the additional volume in the separator located above the waterline. This accounted for 64% of the total separator volume. Oil/water separation had to be enhanced by this change since the fluid residence time increased along with the volume. Only during wave tests using light oil did any oil reach the water discharge pump inlet and then it was very little. This means that the water discharge capacity could be increased beyond what was used in the tests without significantly affecting the performance of the separator. The onboard storage capacity of collected oil was also increased by the modification. The changes also provided oil offloading ports on the deck which could be drawn from during a test to increase the mass flow rate through the skimmer. This was done when the additional pumps were placed on the skimmer.

The non-turbulent collection of oil and water was virtually unchanged by the conversion to a partial vacuum skimmer. The inlet pipe was extended to within 150 mm of the new decking to deliver the oil to the top of the collected fluid. This prevented the oil from having to rise up through the fluid inside the separator and perhaps be swept away with the water under the baffles to the water discharge pump inlet.

The vessel was stable and had a slow wave response. This was due to the water-filled keel and the catamaran-like arrangement of the flotation chambers on both sides of the vessel.

Sealed Deck House

The purpose of the deck house was to determine when oil reached the inlet of the water discharge pipe located 100 mm above the keel of the separator. This would be an indication that the vessel was either full of oil or that the water had been removed from beneath the oil and oil would be offloaded next. Since oil was offloaded from the ports welded flush with the deck and logistics prevented tests with enough oil to fill the skimmer, the deck house was not put to its designed use. It did, however, provide an excellent view of the amount of oil mixed with the water at the bottom of the skimmer. It also provided an additional port from which water could be drawn to increase the mass flow rate through the skimmer.

Oil and Water Offloading Pumps

The gasoline-driven pumps which arrived with the skimmer consisted of a diaphragm pump (7 m^3/hr) for oil offloading and a centrifugal pump (70 m^3/hr) for water discharge. Both pumps performed well until carburetor trouble forced the smaller one out of service. With the increase in usable separator volume the pump capacity could be increased without fear of drawing the collected oil out with the water. It was evident that an increase in mass flow rate over the weir could diminish the turbulence generated by the headwave and thus increase the skimmer's performance at higher tow speeds. To accomplish this an air-driven double-diaphragm pump (32 m^3/hr) was placed onboard to offload from an oil exit port on deck and a gasoline centrifugal pump (16 m^3/hr) was placed onboard to discharge water drawn up into the sealed deck house. The resulting increase in mass flow rate produced an increase in performance in both calm water and in waves. Judging from the general absence of oil exiting with the discharged water the pump rate could be increased to about 225 m^3/hr without deleterious effects. This would give a fluid residence time of about 100 seconds in the separator. Since the oil enters the separator only loosely mixed with the water, this should be enough time to stabilize at the top of the separator and not be drawn out with the discharged water.

OPERATIONS DISCUSSION

There were several operational procedures carried out during the test program which would not be used in field operations. They are listed and described below:

Tie Lines

The skimmer was secured at its forward end to the main bridge for towing and at its stern for security in stopping and for towing lines when the bridge returned to the north end of the tank following a test run. These lines were kept taut to prevent the skimmer from pitching a great deal and causing excessive shock loading to the bridges. The result was that vessel response to waves was reduced. It is possible that better vessel response would affect recovery performance.

Constant Tow Speed

In field operations a self-propelled, pushed or even towed vessel may be slowed somewhat when encountering an oncoming wave. The slow-down reduces the impact forces between the wave and the vessel. The oil-entraining turbulence generated by the encounter is subsequently reduced. During testing the vessel is not allowed to slow when encountering waves, so it plows through them. The turbulence and shock produced in the skimmer head by the encounter may have had an adverse effect on device performance.

Head Seas

During these tests, the device was towed only towards the wave generator. Since the skimming head reacted poorly to waves and since stern seas typically provide a "quieter" situation for a floating, moving vessel, the results gained from wave tests should not be construed to apply to following-sea conditions also.

Limited Tow Time

The length of test run was limited to about 100 meters due to the size of the test tank (200 meters) and the clearance necessary for equipment, slow acceleration, and safe braking. In actual field operations the skimmer may be towed for thousands of meters before it is turned or stopped. During certain tests the oil headwave in front of the weir, between the oil guide booms was seen to advance away from the weir as the test proceeded. This indicated the oil was not being taken into the skimmer at the same rate it was being distributed from the main bridge. A lengthy tow would have resulted in the headwave progressing out beyond the oil guide booms and oil being lost. Increasing the pumping rate aboard the skimmer or setting the weir at a different depth might have corrected the situation but thoroughly investigating such changes was beyond the scope of this project.

A better idea of the possible RE capability of the skimmer could have been obtained if the tow was long enough to allow more oil to enter the skimmer and build up a thick layer on top of the water inside the separator. This would have allowed the offloading of a greater amount of oil before water was drawn with it. In addition, a longer oil/water separation time would have been available before the oil was offloaded. The situation would not be unlike an actual oil spill response operation.

DATA DISCUSSION

Note that Figures 13 and 14 show "corrected" values of ORR. Tests were typically run with a nominal 12-mm slick thickness, and measured values of ORR were later adjusted by multiplying by 12 mm and diving by the actual slick thickness. This is not necessary or appropriate for TE or RE.

The effects that the independent variables had upon TE and ORR are listed below. RE was not recorded for each test since less than halfway through the program the oil was offloaded during the test rather than following it. Offloading during the test drew an uncontrollable amount of water with the oil which lowered the RE of the device. Under such circumstances comparison of the RE's would not render useful conclusions as to the causes of the differences. The quantities of oil offloaded into the barrels gave representative values of RE if the barrel was not drained of much water before the sample was taken. This was the case in several tests while the procedure was to offload the oil after completion of the test run. The values obtained were 86% for 0.5 kts, 91% for 0.75 kts, 91% for 1.0 kts, 89% for 1.25 kts, 88% for 1.5 kts and 87% for 2.0 kts. These values should be considered below the capability of the skimmer since the amount of oil in the one full barrel represented 70% of the oil collected by the skimmer. As the oil was drawn from the skimmer the oil layer inside decreased to where water was drawn out with the oil. This lowered the percentage of oil in the outlet stream and subsequently that in the barrel also.

There was not enough time in the test program to optimize device settings for every condition tested so the test results should not be considered the best performance possible by the skimmer. When time allowed, device settings were changed and tests were run under the same tank conditions. The best results from such tests at the same tow speed are plotted as "maximum performance" values in the graphs.

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Tow Speed

The effect of increasing tow speed was to raise a head wave in front of the floating head and create turbulence by forcing more water to be channeled from the sweep width of the head (1.2 m) down to the width of the weir (0.5 m). By comparing the flow over a rectangular weir (1.2 m wide) at different water depths over the weir to the tow speeds and pumping capacity of the skimmer the tow speed where performance would begin to decline should be predictable. Using one pump 70 m^3/hr of water could be discharged. The water depth over a 1.2 m wide rectangular weir necessary for a flow of 70 m^3/hr is 4.0 cm.[1] The tow speed which produces a headwave of 4.5 cm is 1.86 knots (from Bernoulli's equation). The graphs of tow speed versus TE and ORR (Figures 11, 12, 13 and 14) show that the decline in performance occurred between 1.5 and 2.0 knots. Using four pumps (125 m^3/hr) the point of decline should be at about 2.2 knots. The graph of TE versus tow speed in heavy oil and calm water shows a significant decline in performance above 2 knots using four pumps. The extrapolation of these results suggest that a greater pumping capacity would result in better performance at higher tow speeds. As long as the current inside the skimmer is not large enough to entrain and sweep a good deal of oil to the water discharge inlet performance will increase with pumping capacity.

Waves

TE and ORR performance was greatly decreased by the presence of waves. Below 0.75 knots in harbor chop waves the oil was washed away from the skimming head by the wave reflection. Above 1.0 knots TE performance declined to less than 50% in the harbor chop. This was due to the inability of the skimming head to respond well with the waves which caused turbulence in front of the weir and allowed waves to splash over the head. ORR values level out and begin declining at 1.0 knots in the HC as compared to 1.5 knots in calm water.

Regular waves produced poorer skimmer performance than the harbor chop. The harbor chop condition varied the water level at the weir at a greater frequency than the regular waves. The skimmer head heaved only slightly during the harbor chop and the waves slapped into and over the weir. In regular waves the skimming head heaved a great deal and was often 180° out of phase with the oncoming waves. A great deal more turbulence was generated in front of the weir and more waves splashed over the skimming head resulting in the poorer performance. A redesign of the skimming head and inlet hose should increase performance in waves at all tow speeds.

Oil Viscosity

Skimmer TE and ORR performance was superior in the heavier oil. Driven by the turbulence created in front of the weir, the lighter oil tended to mix with the water and pass beneath the skimming head. Although the TE results were consistently lower in the light oil, the general trends in performance were very similar. The light oil reached the water discharge inlet during tests in waves, while the heavy oil did not. The amount of oil discharged with the water was insignificant, but it points to a possible problem of discharging oil if the pumping capacity is increased.

Weir Depth

This variable was not investigated completely since the skimming head rose up in the water if the fluid in its sump was lowered very much. Generally, the weir was kept at about 60 to 70 mm deep in calm water. In wave tests the weir depth varied a great deal due to the poor wave response capability of the skimming head. However, in wave tests, skimmer performance was increased if the weir was set at a depth of about 100 or 120 mm before the start of the test. The lower setting further submerged the shovel nose of the skimming head and reduced its presence above the water's surface where it produced oil-entraining turbulence.

Slick Thickness

TE was not noticeably affected by the changes in slick thickness; however, ORR varied in direct proportion to the changes.

Recovery efficiency samples indicate the device is capable of consistently high values of RE.

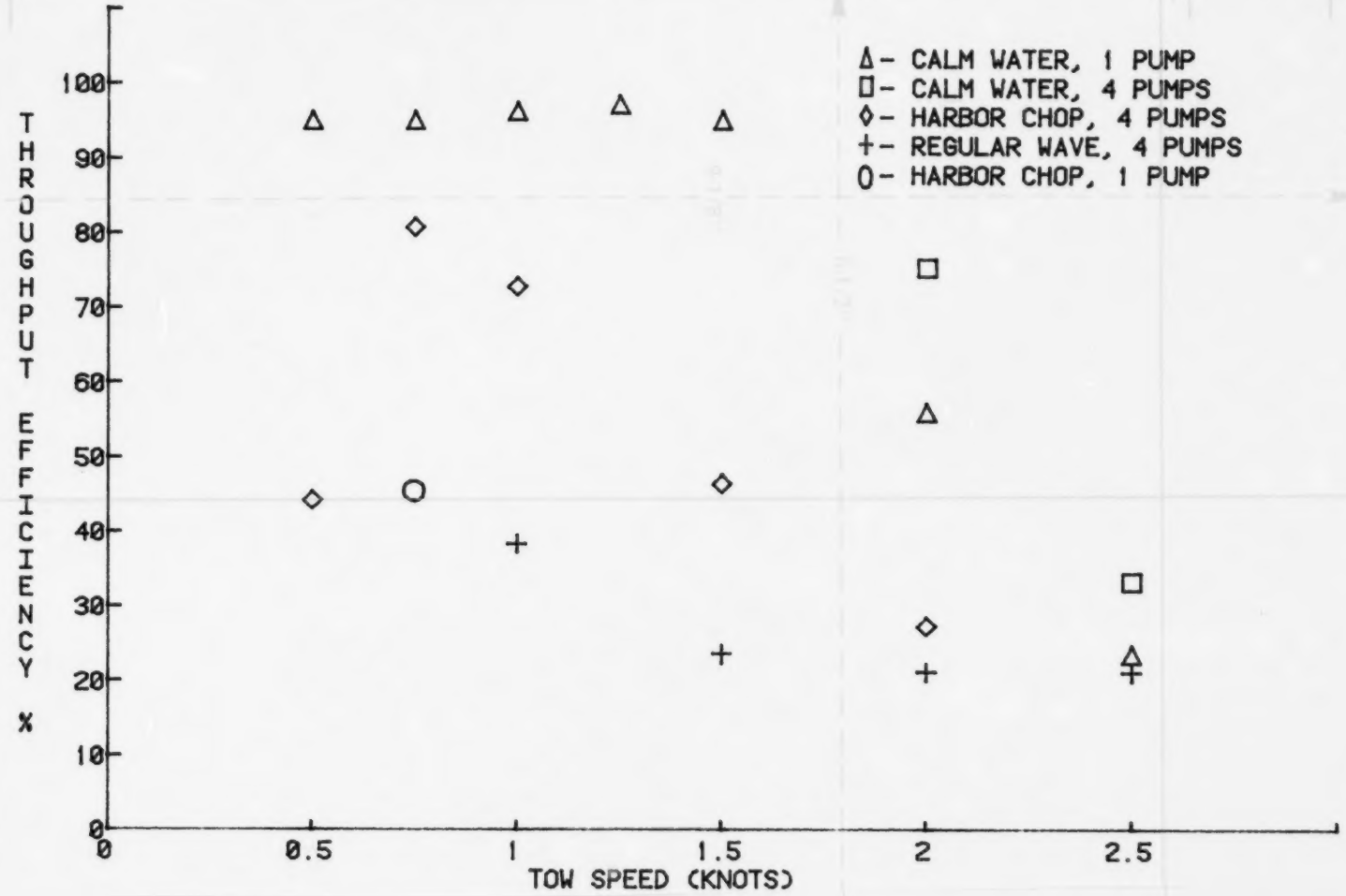

Figure 11. Maximum TE data for the DiPerna Sweeper using heavy oil.

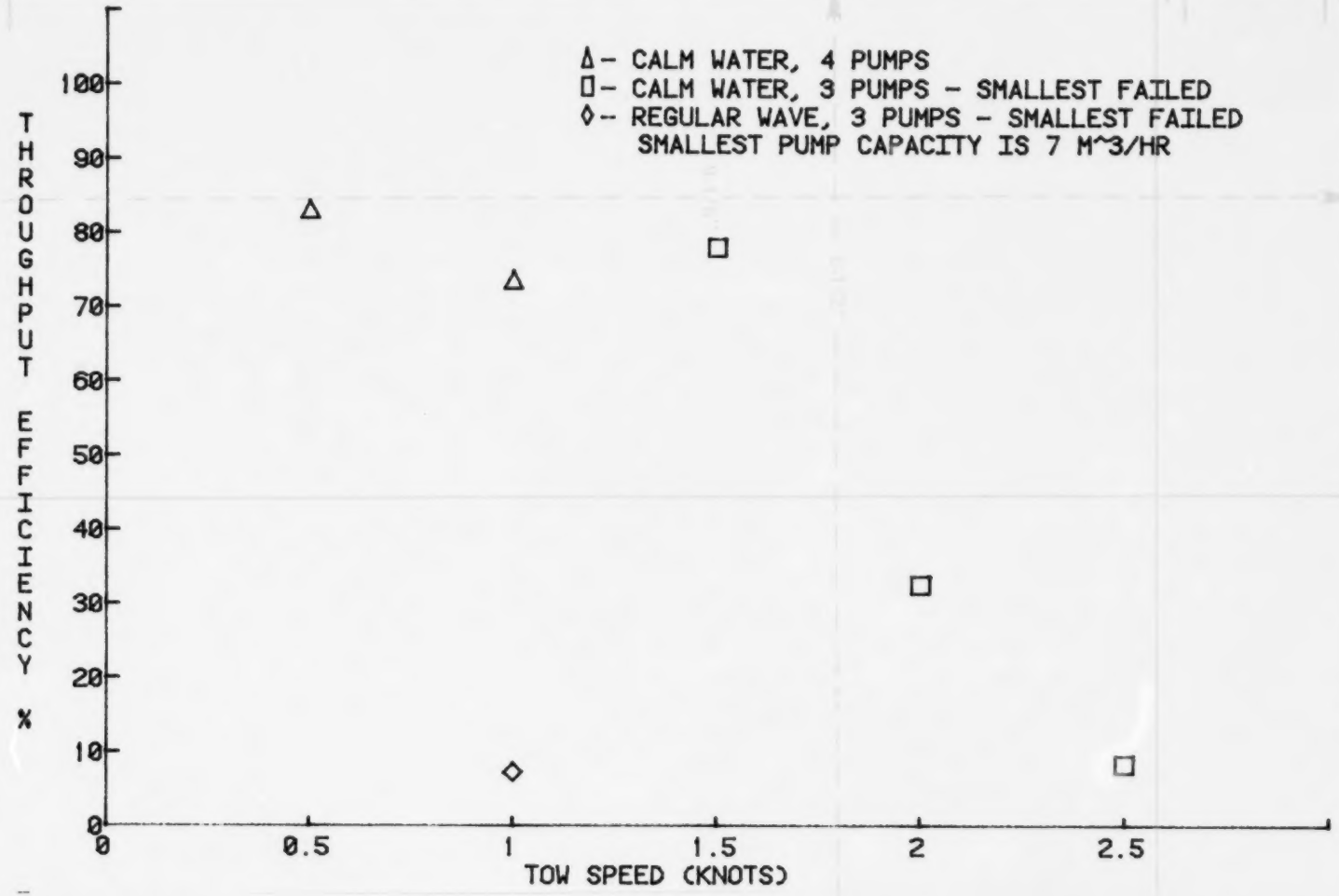

Figure 12. Maximum TE data obtained for the DiPerna Sweeper in light oil.

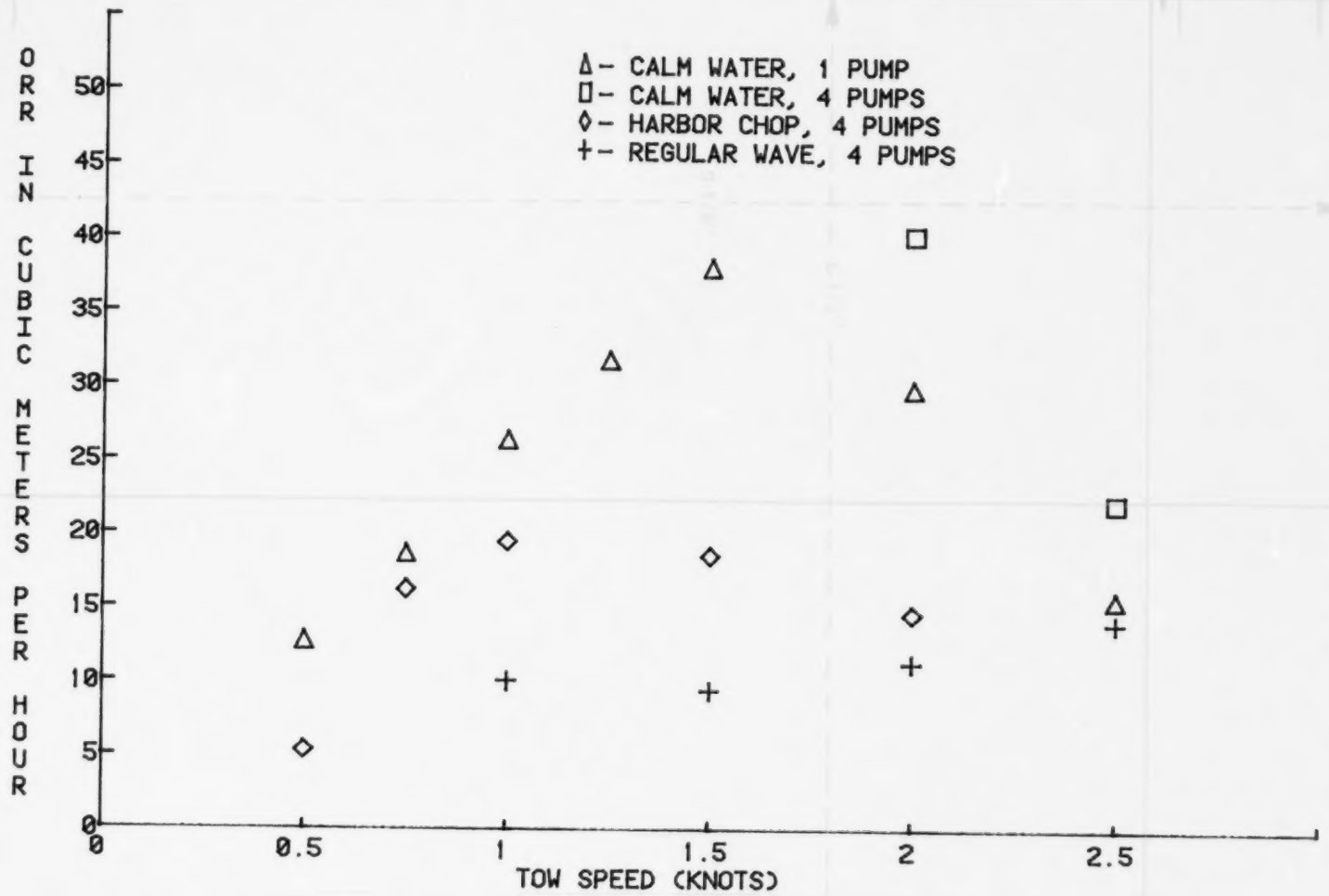

Figure 13. Maximum oil recovery rates obtained for the DiPerna Sweeper in tests with heavy oil.

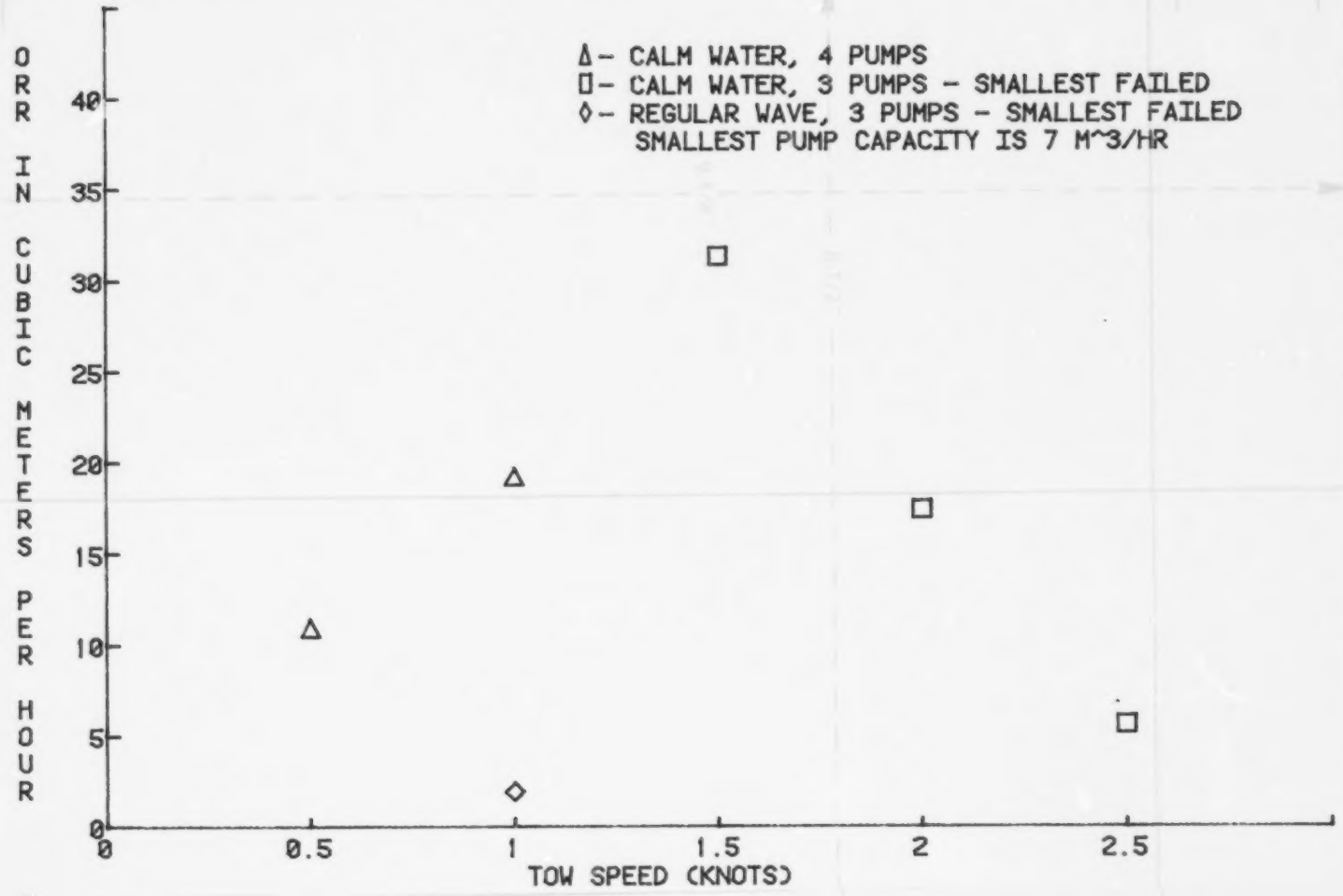

Figure 14. Maximum oil recovery rates obtained for the DiPerna Sweeper in tests with light oil.

APPENDIX A

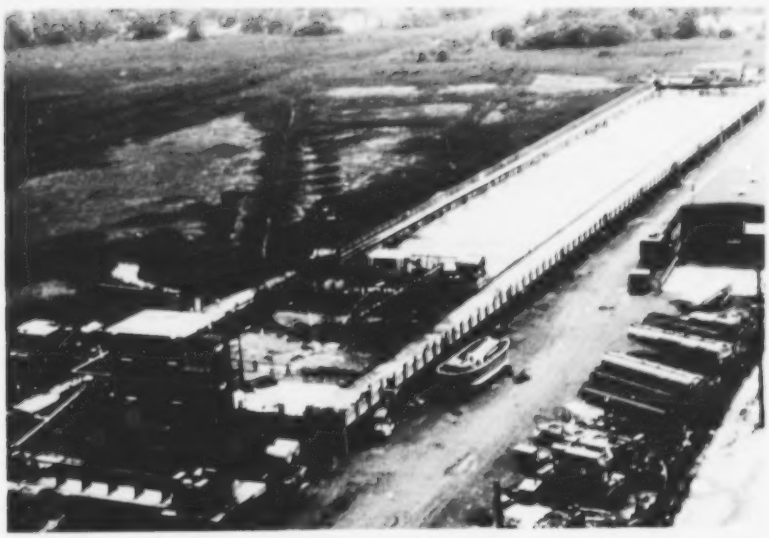

Figure A-1. Aerial view of OHMSETT Facility.

The U.S. Environmental Protection Agency operates the Oil and Hazardous Materials Simulated Environmental Test Tank (OHMSETT) located in Leonardo, New Jersey. This facility provides an environmentally safe place to conduct testing and development of devices and techniques for the control and clean-up of oil and hazardous material spills.

The primary feature of the facility is a pile-supported, concrete tank with a water surface 203 meters long by 20 meters wide and with a water depth of 2.4 meters. The tank can be filled with fresh or salt water. The tank is spanned by a bridge capable of exerting a horizontal force up to 151 kilonewtons while towing floating equipment at speeds to 6.5 knots for at least 40 seconds. Slower speeds yield longer test runs. The towing bridge is equipped to lay oil or hazardous materials on the surface of the water several meters ahead of the device being tested, so that

reproducible thicknesses and widths of the test slicks can be achieved with minimum interference by wind.

The principal systems of the tank include a wave generator, a beach, and a filter system. The wave generator and absorber beach can produce regular waves to 0.6 meter high and to 45 meters long, as well as a series of 0.7 meters high reflecting, complex waves meant to simulate the water surface of a harbor. The tank water is clarified by recirculation through a 410 cubic meter/hour diatomaceous earth filter system to permit full use of a sophisticated underwater photography and video imagery system and to remove the hydrocarbons that enter the tank water as a result of testing. The towing bridge has a built-in oil barrier which is used to skim oil to the North end of the tank for cleanup and recycling.

When the tank must be emptied for maintenance purposes, the entire water volume of 9800 cubic meters is filtered and treated until it meets all applicable State and Federal water quality standards before being discharged. Additional specialized treatment may be used whenever hazardous materials are used for tests.

Testing at the facility is served from a 650 square meters building adjacent to the tank. This building houses offices, a quality control laboratory (which is very important since test fluids and tank water are both recycled), a small machine shop, and an equipment preparation area.

This government-owned, contractor-operated facility is available for testing purposes on a cost-reimbursable basis. The operating contractor, Mason & Hanger-Silas Masor. Co., Inc., provides a permanent staff of eighteen multi-disciplinary personnel. The U.S. Environmental Protection Agency provides expertise in the area of spill control technology and overall project direction.

For additional information, contact: Richard A. Griffiths, OHMSETT Project Officer, U.S. Environmental Protection Agency, Research and Development, MERL, Edison, New Jersey 08837, telephone number 201-321-6629.

APPENDIX B

OHMSETT test oils used for the DiPerna Sweeper test program.

Type	Viscosity ($10^{-6}m^2/s$@^oC)	Specific gravity	Surface tension ($x10^{-3}N/m$)	Interfacial tension ($x10^{-3}N/m$)
Circo X Heavy	1419 @ 18°	0.937	32.5	12.9
Circo 4X Light	44.8 @ 20.5°	0.913	28.9	5.2

Circo oil is produced by the Sun Oil Co., Inc. headquartered in Philadelphia, PA.

OHMSETT waves used for the DiPerna test program.

	Wave Generator			
Type	Stroke (cm)	RPM	H 1/3 (m)	Length (m)
0.3 m harbor chop	7.6	40	0.3	---
0.4 m regular wave	19	15	0.4	11.6